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# MASS TRANSFER MECHANISMS IN A HETEROTROPHIC BIOFILM

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## ABSTRACT

The diffusion coefficient of three different chemical species in naturally grown, heterotrophic biofilms have been measured. The mechanical structure of the biofilm matrix reduces the molecular diffusion to about 50 to 60 % of the value in pure water. Depending on the roughness of the biofilm surface and the flow conditions eddy diffusion increased the mass transfer into the biofilm near the surface.
The influence of the diffusion potential and the donnan potential on the ions have been evaluated by comparing the diffusion coefficients of a positively and negatively charged ion and a neutral molecule in experiments with different background electrolyte concentrations. Mass transfer effects by electrostatic forces are negligible at the ionic strength of waste water and tap water.

## INTRODUCTION

The substrate uptake rate of most biofilm systems is limited by mass transfer. Biofilm models generally use an average diffusion coefficient over the entire biofilm depth.

The scope of this investigation is:

- determination of molecular diffusion in naturally grown biofilms
- contributions of eddy diffusion to mass transfer
- influence of electrostatic forces on diffusion of charged chemicals

## METHODS

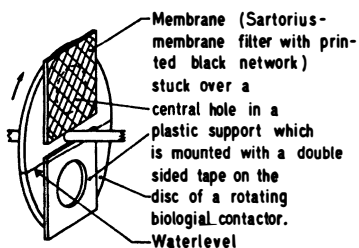



Fig. 1
Heterotrophic biofilms were grown directly on membranes. A rotating biological contactor served as a laboratory reactor.

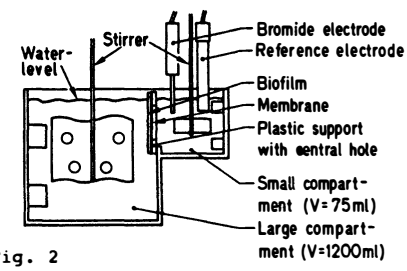
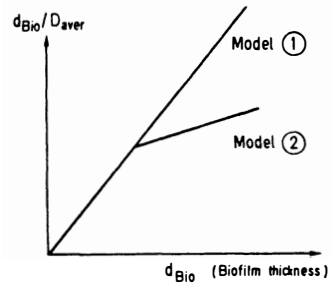



Fig. 2
Mass transfer was observed in a two-cell system for the three chemical species bromide, sodium and glucose.

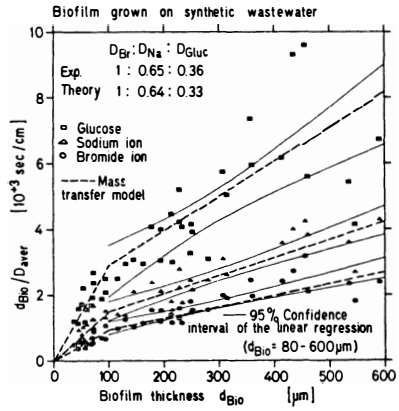
## RESULTS

MECHANICAL MASS TRANSFER RESISTANCE OF THE BIOFILM




The average diffusion coefficient in the biofilm matrix ($D_{aver}$) is constant over the whole biofilm depth.

Above a certain biofilm thickness, eddy diffusion in the upper part of the biofilm increases $D_{aver}$.



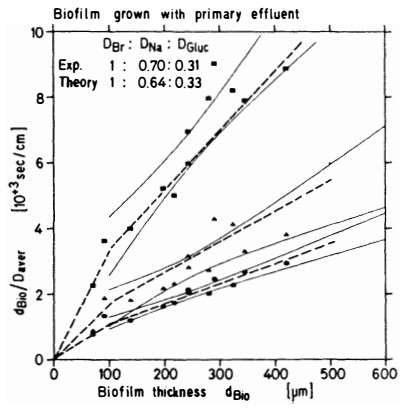




Fig. 4

The average diffusion coefficient in the biofilm matrix ($D_{aver}$) increases with increasing biofilm thickness. The observed value varies from a low 40 % to a high 170 % of the corresponding value in pure water. This apparent increase of the diffusion coefficient can be explained by advective processes (eddy diffusion) in the biofilm matrix close to the biofilm surface and a density change of the biofilm during growth (Hoehn and Ray, 1973). The irregularities and filaments of the biofilm surface penetrate through the laminar waterfilm layer. Therefore the turbulent zone reaches the surface of the biofilm and produces eddy diffusion in the biofilm matrix near to the surface. Jansen and Kristensen report likewise diffusion coefficients of more than 100 % of the value in pure water for denitrifying biofilms.

ELECTROSTATIC EFFECTS

Diffusion potential

The effect of the diffusion potential in the biofilm matrix has been observed by comparing the diffusion of sodium and bromide ion in presence of an increasing background electrolyte.

For most waste water and tap water, where the concentration of the observed ion is smaller than the background electrolyte, the influence of the diffusion potential can be neglected. Only in experiments with a very low ionic strength and bivalent ions must the influence of the diffusion potential on mass transfer be considered.

Donnan potential

A biofilm matrix contains an excess of fixed negatively charged groups (phosphate- and carboxylic acid-groups). If these groups are evenly dispersed in the matrix, a donnan potential will be formed, that impedes the diffusion of negatively charged ions.

The influence of a donnan potential was not detected for ionic strengths higher than $10^{-3}$ M. This is in contradiction to the conclusion, that Riemer and Harremöes draw from their experiments.

## CONCLUSIONS

- The mechanical structure of the biofilm matrix (1.8 - 2.6 % TS) reduces the molecular diffusion to about 60 to 50 % of the value in pure water.
- Depending on the roughness of the biofilm surface and the flow conditions in the water film above, eddy diffusion may reach into the biofilm matrix near the surface. In this experiment the influence of eddy diffusion was visible at $d_{Bio} > 100\ \mu m$. The appearance of advection in the upper part of the biofilm has the following consequences:
  - -- no external mass transfer resistance
  - -- higher mass transfer in the upper part of the biofilm
- Mass transfer effects by electrostatic forces between ions (diffusion-, donnan potential (Siegrist and Gujer, 1984)) are mostly negligible at the ionic strength of waste water and tapwater.

Results above lead to the conclusion, that besides the diffusion coefficient in the biofilm matrix, it is equally important to know the conditions at the biofilm surface.

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